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Information on abundance and harvest of eastern Hudson Bay beluga (*Delphinapterus leucas*)

Information sur l'abondance et la récolte de bélugas (*Delphinapterus leucas*) de l'est de la baie d'Hudson

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ABSTRACT

Subsistence harvest of beluga whales by Nunavik communities is directed towards a mixture of two summer stocks: the Western Hudson Bay stock (WHB) and the depleted Eastern Hudson Bay stock (EHB). According to harvest statistics, the 2011 hunt consisted of 32 beluga killed near Sanikiluaq (Belcher Islands), 19 in the eastern Hudson Bay, 17 in Ungava Bay, 115 in Hudson Strait in the spring and 86 in the fall. Since 2009, it has been assumed based on genetic data that all animals killed in EHB, 10% of those killed in the spring and summer in Hudson Strait, and 20% of those killed in Ungava Bay and during the fall in Hudson Strait are EHB beluga. It has also been assumed that 12% of beluga killed by Sanikiluaq hunters belong to the EHB stock. Using these proportions, the 2011 harvest was equivalent to 55 EHB beluga, 5 beluga more than prescribed by the management plan.

A population model incorporating updated information on harvest statistics and stock composition was fitted to aerial survey estimates using Bayesian methods. The model estimated that the stock size in 1985 was 4,121 animals with a 95% Credible Interval (CI) of 2,225–8,857. The lowest abundance point occurred in 2001 and was estimated at 2,981 (95% CI 1,963–4,681). The model estimated a 2011 abundance of 3,030 individuals (95% CI 1,256–6535). At current harvest levels, the stock has probably remained stable over the last few years. The model estimated struck-and-loss at 56% (95% CI 22–143%) and growth rate at 2.6% per year (95% CI -3.2% to +8.5%).

To achieve a 50% probability of increase in stock abundance, future harvests should not exceed 49 EHB beluga per year, while lower harvests would likely allow some recovery. Limiting the harvest of EHB animals to 10 individuals would reduce the probability of decline to 25%. Conversely, a harvest of 103 EHB whales would have a 75% probability of leading to a decline. The probability of decline in absence of harvest is 19%. However, the number of animals that can be harvested without causing a decline of the EHB beluga stock will depend on how catches are distributed between Eastern Hudson Bay, Ungava Bay and Hudson Strait, as well as the proportion of spring/summer vs. fall catches in Hudson Strait.

RÉSUMÉ

La chasse aux bélugas à des fins de subsistance par les communautés du Nunavik vise un mélange de deux populations: le stock de l'ouest de la baie d'Hudson (OBH) et celui de l'est de la baie d'Hudson (EBH). En 2011, les prises ont été constituées de 32 bélugas tués près de Sanikiluaq (îles Belcher), de 19 dans l'est de la baie d'Hudson, de 17 dans la baie d'Ungava, de 115 dans le détroit d'Hudson au printemps et de 86 à l'automne. Depuis 2009, il est présumé, sur la base des analyses génétiques, que tous les animaux tués dans l'est de la baie d'Hudson, 10 % des animaux tués au printemps et en été dans le détroit d'Hudson, et 20 % des animaux tués dans la baie d'Ungava et en automne dans le détroit d'Hudson sont des bélugas de l'EBH. Il est également présumé que 12% des bélugas tués par les chasseurs de Sanikiluaq appartiennent au stock de l'EBH. Selon ces proportions, la chasse de 2011 équivaut à 55 bélugas de l'EBH, soit 5 de plus que le nombre prescrit par le plan de gestion.

Un modèle de population intégrant les statistiques de chasse les plus à jour a été ajusté à l'aide de méthodes d'inférence bayésiennes aux estimations d'abondance obtenues à partir des relevés aériens, et a permis d'évaluer la population de 1985 à 4 121 individus avec un intervalle de crédibilité (IC) de 95 % de 2,225–8,857. La population aurait atteint son plus bas niveau en 2001 avec un effectif de 2 981 individus (IC 95% 1,963–4,681). La population de 2011 a été estimée à 3 030 individus (IC 95% 1,256–6535). Aux niveaux de capture actuels, la population semble être restée stable au cours des dernières années. D'après la modélisation, la proportion de bélugas abattus mais perdus est estimée à 56% (IC 95% 22–143%) et le taux d'accroissement à 2,6% par an (IC 95% de -3,2% à +8,5%).

Un prélèvement annuel de 49 individus de l'EBH dans le futur entrainerait un risque de 50% de déclin de la population. Une diminution du prélèvement à 10 individus de l'EBH réduirait la probabilité de déclin à 25%. Inversement, la prise de 103 individus de l'EBH aurait 75% de chances d'entraîner un déclin. En l'absence totale de prélèvement de bélugas de l'EBH, la population aurait quand même 19% de chances de décliner. Cependant, le nombre d'individus qui peuvent être capturés sans provoquer une diminution de la population de bélugas de l'EBH dépend de la répartition des prises entre l'est de la baie d'Hudson, la baie d'Ungava et le détroit d'Hudson de même que des proportions chassées au cours du printemps, de l'été, et de l'automne.

INTRODUCTION

Nunavik communities have traditionally harvested beluga whales (*Delphinapterus leucas*) along the shores of Hudson Bay, Hudson Strait and Ungava Bay (Fig. 1). The targeted beluga belong mostly to two summer stocks: the Western Hudson Bay stock (WHB), which numbers about 57,000 individuals (Richard 2005), and the Eastern Hudson Bay stock (EHB), which was depleted by intensive commercial hunting between the 1860's and the early 1900's and has decreased from an estimated pristine stock size of 12,500 to about 3,000 individuals in 2010 (Doniol-Valcroze et al. 2011).

Current subsistence harvest is directed towards both resident stocks during summer, and towards migrating whales from a mixture of stocks during spring and fall. Aerial surveys flown in the mid-1980's to assess abundance (Smith and Hammill 1986) indicated that high subsistence harvests were limiting recovery of the EHB beluga, which led to restrictions on harvesting through a combination of quotas and seasonal and regional closures (summarized in Lesage et al. 2001; 2009; Lesage and Doidge 2005) to allow for stock recovery (Reeves and Mitchell 1989). Concerns for beluga in the waters adjoining Nunavik also led to the designation of Ungava Bay and EHB beluga as "Endangered" (COSEWIC 2004).

Continued monitoring of changes in the EHB beluga stock is made difficult by limited census data and large uncertainty in abundance estimates (Gosselin et al. 2009). Bayesian statistics are well adapted to data-poor situations because they allow the incorporation of prior existing knowledge of parameter values, including their associated uncertainty. A population model incorporating information on catch levels and stock composition was fitted to aerial survey estimates using Bayesian methods (Hammill et al. 2009). The 2010 update of the model indicated that the current stock size was likely stable but that a harvest exceeding 50 EHB animals would have a 50% probability of causing a decline in the stock (Doniol-Valcroze et al. 2011).

Here we update the population model using harvest data from 2011 to inform management decisions.

MATERIALS AND METHODS

MODEL STRUCTURE

A stochastic stock-production model was fitted by Bayesian methods (for details, see Hammill et al. 2009). Existing information or expert opinions on the values of stock-dynamic parameters were included as prior distributions. Parameter estimates are refined by updating the prior to a posterior distribution based on the data. Predictions are then based on the full multivariate posterior distribution of the parameter estimates.

Population size in each year N_t is a multiple of the previous year's, with removals deducted:

$$N_t = N_{t-1} \cdot \exp(r) \cdot \varepsilon 1_t - R_t$$

where r is the instantaneous growth rate, $\varepsilon 1_t$ is a stochastic term for the process error and R_t are the removals for that year. Removals were calculated as catches corrected for animals that were struck and lost:

$$R_t = C_t \cdot (1 + SL)$$

Survey catchability was assumed to be 1, and survey estimates S_t are linked to population size N_t by a multiplicative error term $\varepsilon 2_t$:

$$\ln(S_t) = \ln(N_t) + \varepsilon 2_t$$

DATA

Census data comprised five estimates from aerial surveys flown in 1985, 1993, 2001, 2004 and 2008 (Table 1). Survey counts were corrected for a decline in detection with distance from the survey platform using standard line-transect methods (Gosselin et al. 2009). Corrections were also applied for "unavailable" animals using: $S_t = S_{survey} / P_0 + S_{estuary}$, where the estimated proportion (P_0) of animals visible from an aerial survey platform is 0.478 (SE 0.0625) (Kingsley and Gauthier 2002). Beluga detected in estuaries ($S_{estuary}$) were assumed to represent total counts. Although estimates of uncertainty were available for each survey estimate, they were incorporated into the fitting process only by guiding the formulation of the prior distribution of the survey error (see below).

Harvest data came from annual reports of landed catches (summarized in Hammill et al. 2009, Lesage et al. 2009). The proportions of landings that belonged to the EHB summer stock were estimated from genetic analyses, and input catch series were revised accordingly (Table 2). Assessments prior to 2009 have used a proportion of EHB animals in the harvest of 21% for Hudson Strait and 13% for Ungava Bay (Hammill et al. 2004). In recent years, genetic analyses have shown changes in these proportions. Although data are lacking on the timing of the hunt for the years prior to 2004, there is a marked difference in the sampled proportion of EHB animals in the fall hunt compared to the spring hunt (Turgeon et al. 2009). Therefore, for this assessment and those of 2009–2010, it was assumed that all animals killed in eastern Hudson Bay, 10% of those killed in the spring and summer in Hudson Strait, and 20% of those killed in Ungava Bay and during the fall in Hudson Strait were EHB beluga. It was also assumed that 12% of beluga killed by Sanikiluaq hunters belonged to the EHB stock.

Spring and summer harvests were composed of 19 beluga taken in the eastern Hudson Bay, 17 in Ungava Bay, 115 in Hudson Strait, and 32 near Sanikiluaq. The fall hunting season in Hudson Strait ended on November 10th with 86 whales caught. Using the proportions defined above, the full harvest is equivalent to 55 EHB beluga, 5 individuals more than allocated by the 2011 management plan.

PRIORS

Bayesian methods require prior distributions to be specified for all random quantities. We used informative prior distributions for the five parameters included in the model: precision terms for the survey and the process errors, a growth rate for the underlying exponential-growth model, a correction factor for the landed catch to allow for struck-and-lost animals, and an initial population size value (1985).

The instantaneous rate of growth, r, was given a uniform prior in the range -0.1 to +0.2. The struck-and-lost correction was given a moderately informative log-normal prior with quartile points at 0.43 and 0.85.

The stochastic process error terms $\varepsilon 1_t$ were given a log-normal distribution with a zero mean. The precision parameter for this lognormal distribution was assigned a moderately informative prior following a bounded gamma (1.5, 0.001) distribution. These parameters were chosen so that the resulting coefficients of variation (CV) would have quartiles of 5.5% and 8.7%.

The survey error term $\varepsilon 2_t$ also followed a log-normal distribution with a zero mean. Its precision parameter was given a moderately informative prior following a gamma (2.5,0.4) distribution.

These parameters were chosen so that the resulting CV on the survey estimates would have quartiles of 35% and 55%, which are approximately equivalent to the range of actual CV for the survey abundance estimates.

MODEL IMPLEMENTATION AND DIAGNOSTICS

The model was run in WinBUGS. Typically, models of this kind produce highly correlated chains in MCMC sampling, so every 40th point was kept from 3 chains of 1,000,000 iterations, after a burn-in of 50,000 samples, for a total of 75,000 samples. We tested for mixing of the chains using Geweke's test of similarity between different parts of each chain, and for convergence between chains using the Brooks-Gelman-Rubin (BRG) diagnostic (which compares the width of 80% Credible Interval (CI) of pooled chains with the mean of widths of the 80% CI of individual chains).

The relative contributions of the parameters to the model were examined by estimating the pD statistic, which is a diagnostic statistic for Bayesian analyses corresponding roughly to the 'effective' number of parameters being fitted. We also tested the sensitivity of the results to the values of two hyper-parameters: β_s used in the prior distribution of the survey error, and τ_{SL} used in the prior distribution of the struck-and-lost factor. For this, we ran versions of the model with five different values of each hyper-parameter and examined the influence of these parameters on the final population estimate as well as on the posterior distributions of the parameters themselves. For logistical reasons, these runs had fewer iterations (400,000 after a burn-in of 10,000, resulting in a thinned chain of 10,000 samples), but their point estimates were similar to those of the main model.

FUTURE PROJECTIONS AND HARVEST SCENARIOS

The model was extended into the future for 10 years at 15 different catch levels (ranging from 0 to 200 whales) to produce predictions of stock trajectories expressed both as stock size and as the probability of stock decrease (from the estimated 2011 stock size).

RESULTS

MODEL CONVERGENCE

Each of the three chains showed rapid mixing and reached a stationary distribution (Geweke's diagnostic, all Z-scores < 2). Trace plots showed that the three chains with different initial values converged quickly to the same distribution (Fig. 2a). This was confirmed by the overall BGR statistic of $\hat{R}$ = 1.0001. When plotted over increasing numbers of iterations, $\hat{R}$ stabilized at less than 1.1 within a few hundred iterations and less than 1.01 after ~2,000 iterations (Fig. 2b).

MODEL ESTIMATES AND UPDATE OF PRIORS

Posteriors distributions of the model parameters are shown in Fig. 3, along with their prior distribution. The estimated rate of growth *r* of 2.6% (95% CI -3.2 to +8.5%) is within the range expected for other cetaceans with similar life histories. Its value was well updated from its prior distribution (median=5%, 95% CI -9.3 to +19.2%). The initial (1985) stock size was also well updated from its prior value, In contrast, the struck-and-lost factor was estimated at 56% (95% CI 22–143%), a minor update from its prior value of 61% (95% CI 23–161%).

The other two priors were either not, or only slightly, updated (the pD index showed the model had only about 2½ 'effective' parameters). Notably, the informative prior for process error was not updated. There were only minor changes to the posterior distribution of the survey error.

SENSITIVITY TO PRIORS

We anticipated high sensitivity of estimated parameter distributions for parameters where the posterior was very similar to the prior (struck-and-lost, survey error, process error). The mean and median of the 2011 stock estimates were little influenced by changes in the hyper-parameter β_s used in the prior distribution of the survey error (Fig. 4). The standard error, however, increased markedly with increasing values of β_s (which increase the CV of survey estimates). In other words, increasing the uncertainty of aerial survey estimates increased the uncertainty around the 2011 abundance, but not its point estimate.

In contrast, changes in the hyper-parameter τ_{SL} used in the prior distribution of the struck-and-lost factor had no perceptible influence on the 2011 point estimates of the stock size or on its uncertainty (Fig. 5). This was surprising because changes in the prior distribution of the struck-and-lost factor had a strong influence on its own posterior distribution (Fig. 6a), suggesting that there is little information in the data about the true value of this factor. We noted that the struck-and-lost factor was only slightly correlated with the final abundance estimate (ρ=0.06), but was more strongly associated with the rate of growth r (ρ=0.28), suggesting that the model compensates for higher or lower struck-and-lost factors by adjusting the growth rate accordingly. This is confirmed by an examination of the sensitivity of posterior distributions of r to different priors of struck-and-lost (Fig. 6b), which shows that the mean value of r varies from 1.46% to 3.38% with different values of hyper-parameter τ_{SL}.

Sensitivity to changes in the prior distribution of the process error was investigated in details in Hammill et al. (2009, table 5) and was shown to have negligible impact on stock size estimates. Moreover, a model with deterministic dynamics (i.e., no process error) yielded results that were very similar to those of the model incorporating some stochasticity, suggesting that further investigation was unnecessary.

POPULATION TRAJECTORY AND PROJECTIONS

The model estimated a 1985 stock size of 4,121 animals with a 95% CI of 2,225–8,857. The lowest abundance point was estimated for the year 2011 at 2,981 individuals (95% CI 1,963–4,681), with a 2011 abundance of 3,030 individuals (95% CI 1,256–6535). At current harvest levels, the stock abundance has probably remained stable over the last few years (Fig. 7).

According to the model, removing 49 EHB animals per year for 10 years would have a 50% probability of causing a decline in the stock relative to its 2011 estimate (Fig. 8). Limiting the harvest of EHB animals to 10 animals would reduce the probability of decline to 25%. Conversely, a harvest of 103 EHB beluga would have a 75% probability of leading to stock decline. In the absence of harvest, the probability of decline is 19%.

DISCUSSION

POPULATION MODELLING

Modelling of this stock is based on only five aerial survey estimates, all of them characterized by substantial uncertainty. Additional uncertainty is associated with the estimated maximum rate of increase of the stock, correction factor for diving animals, and estimates of struck-and-loss. We had to make certain assumptions about the values and distributions of these parameters, which are represented in the model by statistical distribution instead of single values. Sensitivity analyses have shown that these assumptions only have a small impact on model point estimates but can have a strong effect on the uncertainty around those estimates.

The reliability of the model estimates depends on the accuracy of harvest data. Uncertainty in the proportions of EHB beluga in the harvest of regions other than eastern Hudson Bay (i.e., Belcher Islands, Hudson Strait, Ungava Bay) can have a strong impact on the model input R_t, which in turn will influence the model outputs. In its present form, the model does not include uncertainty around these proportions.

The model estimates a high level of struck-and-lost (> 55%). However, this term also includes the effects of under-reporting (of which struck-and-lost is a subset). Moreover, if we are under-estimating the proportion of EHB animals taken in the hunt, then this will be in part reflected in the value for the estimated struck-and-lost term. Nonetheless, a high struck-and-lost value indicates the need for further research, either to improve estimates of the declared harvest or to reduce the number of whales struck and lost. This would also result in an increase in numbers of whales available to communities, without increasing overall harvest levels. Or conversely, a reduction in struck-and-lost rates could reduce the harvest impact on this stock, without having to lower total allowable takes.

POPULATION TRAJECTORY AND HARVEST LEVELS

Under recent management plans, yearly harvest levels have declined and the model suggests that the rate of decline in the EHB beluga stock has also slowed or stopped. However, there is no indication of population growth. The model indicates that a removal of more than 49 animals from the EHB stock, i.e., a harvest similar to what has been allowed over the last 4 years, would have a 50% or higher risk of causing a stock decline. There is currently no stated objective for managing the Nunavik beluga harvest. Setting catches at levels of around 50 EHB whales per year is not precautionary, and rebuilding the resource even to levels observed in the early 1980s is unlikely using this management strategy.

Different approaches could be used to reduce the impact of the harvest on the EHB summer stock, while ensuring access to animals in Hudson Strait. A spring/summer harvest in Hudson Strait, with no harvest in EHB would have the lowest impact on the EHB stock, followed by a fall harvest in Hudson Strait only, again with no harvest allowed in EHB. If harvesting does occur in EHB, then numbers taken in Hudson Strait must be reduced, but the size of this reduction will depend on whether hunting occurs in the spring/summer or in the fall.

POTENTIAL FOR A PRECAUTIONARY APPROACH

Canada is a signatory of the United Nations Agreement on Straddling and Highly Migratory Fish Stocks (UNFA), which came into force in 2001, and commits Canada to use the Precautionary Approach in managing straddling stocks as well as, in effect, domestic stocks. In 2003, the Privy Council Office, on behalf of the Government of Canada published a framework applicable to all federal government departments that set out guiding principles for the application of precaution to decision making about risks of serious or irreversible harm where there is a lack of full scientific certainty. In 2009, management of beluga in Nunavik, fell under the responsibility of the Nunavik Marine Wildlife Management Board. As a result the Board is responsible for providing Total Allowable Take recommendations to DFO. Developping a precautionary framework would likely facilitate sustainable management of Nunavik beluga and recovery of this stock.

In 2006, DFO developed its own Precautionary Approach framework. This identifies three zones of risk: a healthy zone, cautious zone and a critical zone, depending on the status of the resource. When a population is in the healthy zone, then socioeconomic concerns are considered to be the most important when setting harvest levels. However, if the population declines into what is identified as the cautionary zone, then conservation is to assume an increasingly important role in the decision making process. If the population declines further and falls into the critical zone, then conservation is to become a priority and harvest levels should be

reduced to a minimum or stopped to allow the population to recover. There is some flexibility in establishing the threshold separating the three zones. One possibility would be to borrow from the approach used to manage Atlantic seals and to set the precautionary level separating the healthy zone from the cautious zone at 70% of the estimated pristine stock size, i.e. 8,800 animals if the pristine stock size was 12,500 (DFO 2005), The limit reference level which separates the cautious zone from the critical zone would be set at about 2,800 animals for EHB beluga using the framework developed for fish, or at about 3,750 animals using the framework developed for seals. At a current stock size of about 3,000 animals, the EHB summer stock would fall into the lower end of the cautious zone or in the critical zone, depending on where the limit reference level is set in a Precautionary Framework (Fig. 9).

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Table 1. Aerial survey estimates of the beluga summer stock in eastern Hudson Bay. The 1985 survey data were adjusted to account for differences between strip-transect and line-transect methods (Hammill et al. 2004). Aerial survey estimates have been corrected for diving animals (Kingsley and Gauthier 2002) and corrected for estuary animals by adding in estuary counts in EHB of 474, 18, 39 , 5 and 0, for 1985, 1993, 2001, 2004 and 2008, respectively (Hammill et al. 2009).

Year	Distance line-transect (±SE)	Estimate corrected for diving animals (±SE)
1985	*2,294*	4279 (±620)
1993	1,314 (±489)	2727 (±1,012)
2001	1,418 (±635)	2922 (±1,368)
2004	2045 (±698)	4269 (±1,499)
2008	1,265 (±570)	2646 (±1,959)

Table 2. Number of eastern Hudson Bay animals removed from the stock. For the 1985-2008 period, assumed herd composition was: Hudson Bay (100%), Sanikiluaq (12.6%), Hudson Strait (21%), and Ungava Bay (12.6%), regardless of season. For 2009–2011, it is assumed that 10% of animals killed in the spring and summer in Hudson Strait, and 20% of those killed in Ungava Bay and during the fall in Hudson Strait are EHB beluga.

Year	Harvest of EHB whales
1985	84
1986	69
1987	81
1988	76
1989	144
1990	77
1991	144
1992	99
1993	105
1994	128
1995	103
1996	101
1997	98
1998	102
1999	106
2000	104
2001	129
2002	49
2003	54
2004	43
2005	41
2006	29
2007	59
2008	53
2009	38
2010	51
2011	*55*

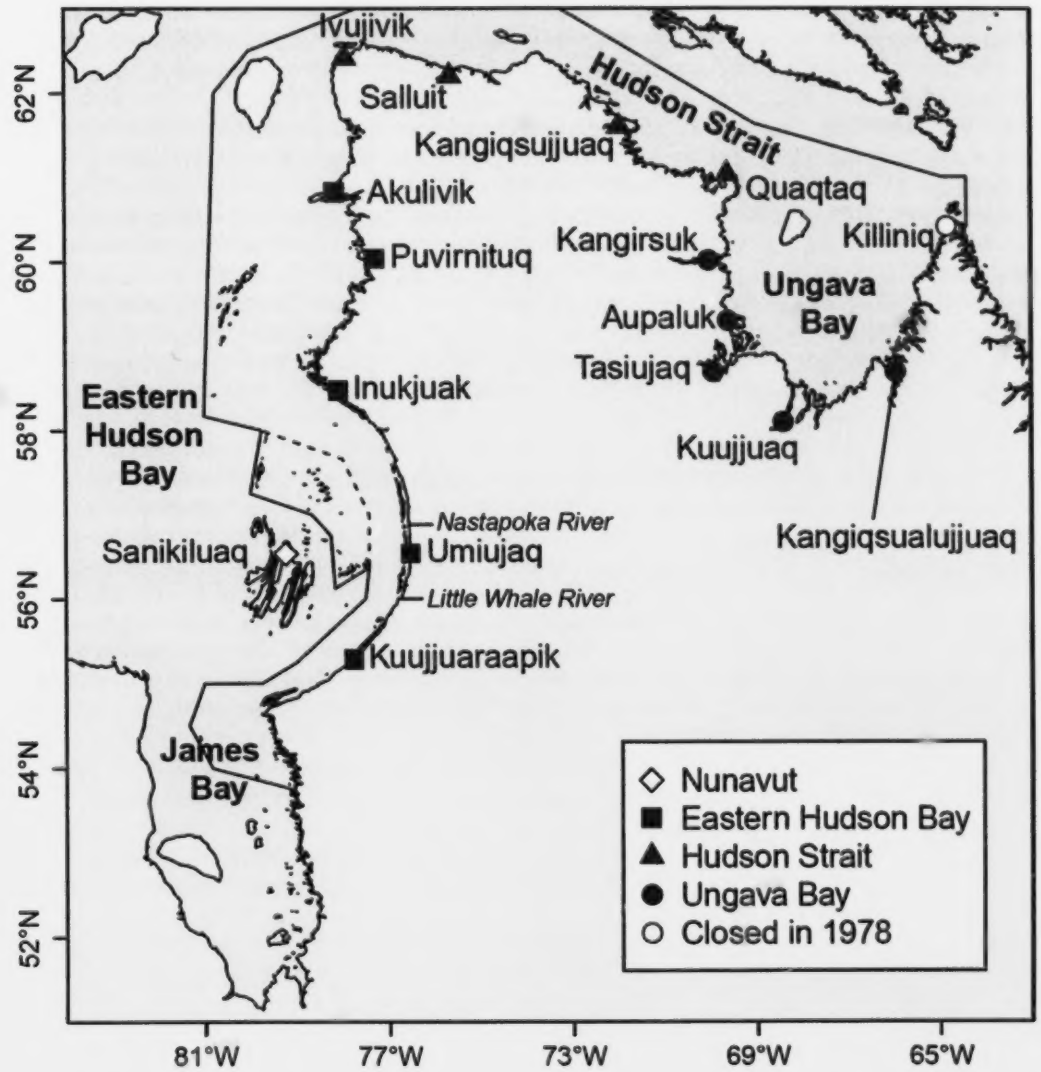

Figure 1. Map of communities in Nunavik and limits of Nunavik Marine Region (solid line) and Equal Use and Occupancy Area (dashed line).

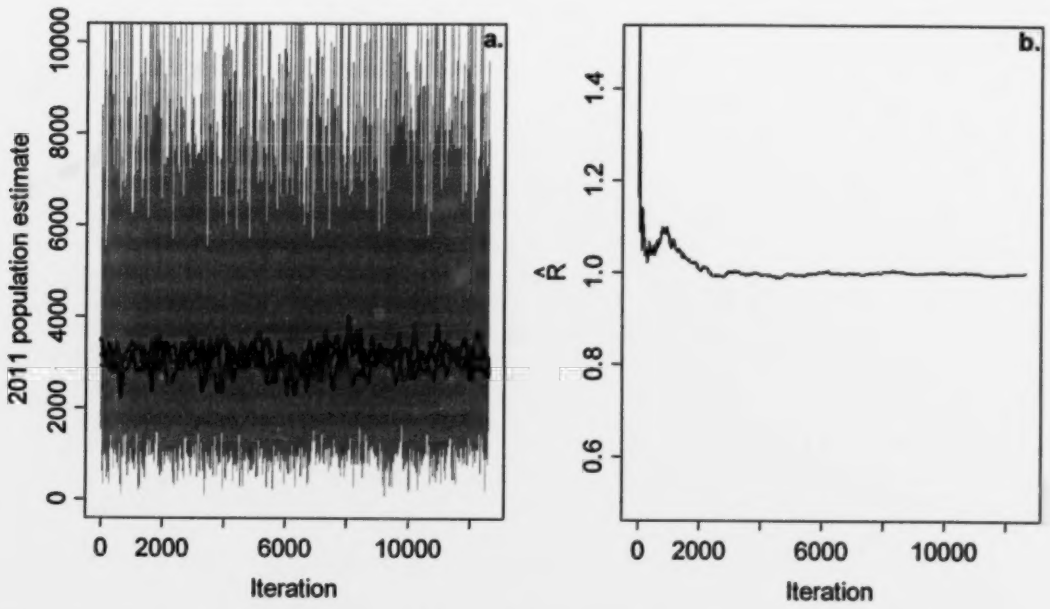

Figure 2. a) Trace plot of the first 12,000 iterations of the three MCMC chains (gray lines) for the final population estimate. The smoothed traces of the three chains (blue, green and red bold lines) show good mixing and convergence. b) BGR convergence diagnostic of the three chains, plotted for increasing numbers of iterations. Values close to 1 indicate good convergence.

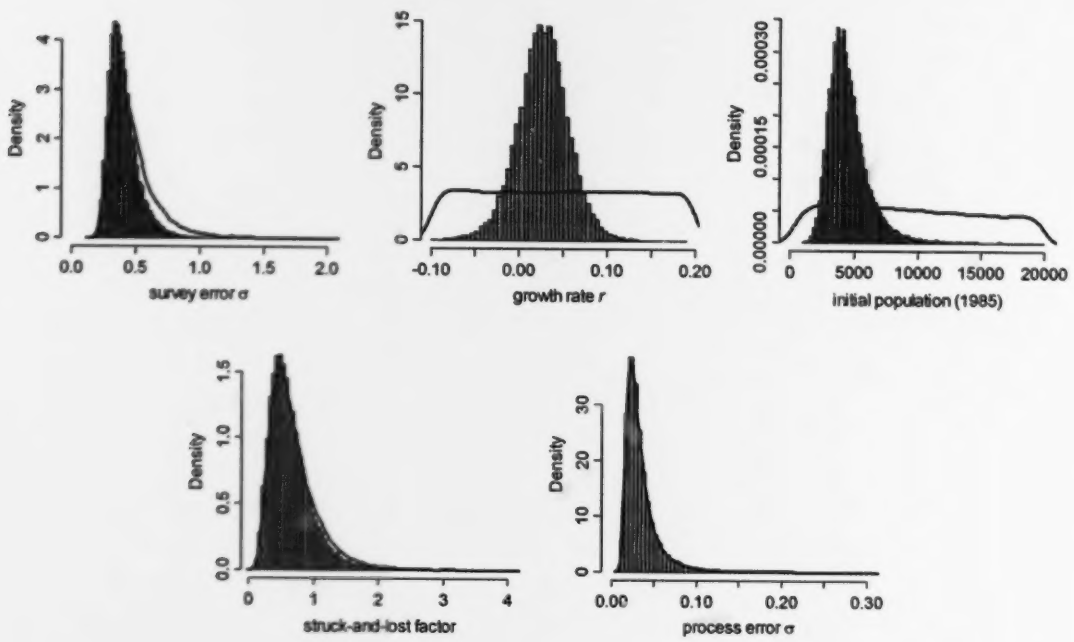

Figure 3. Prior (lines) and posterior (bars) distributions of the five parameters estimated by the beluga population model.

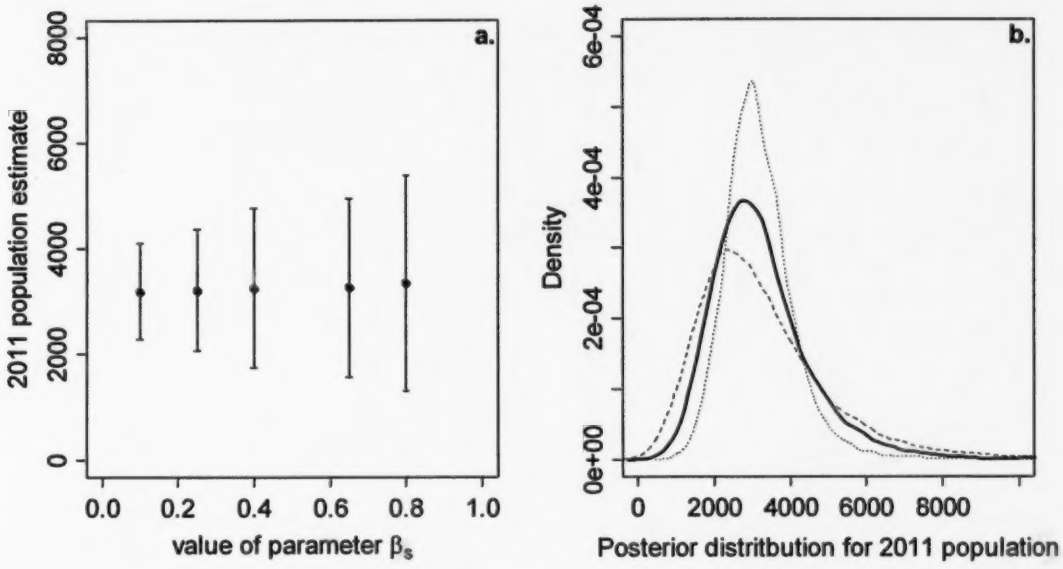

Figure 4. Sensitivity of model population estimates to the hyper-parameter β_s used in the prior distribution of the survey error. *a) Mean of population estimates (±SE) for five values of β_s. b) Posterior density distribution of 2011 population estimates for β_s = 0.4 (solid line, value used in main model), β_s = 0.1 (dotted line) and β_s = 0.8 (dashed line).*

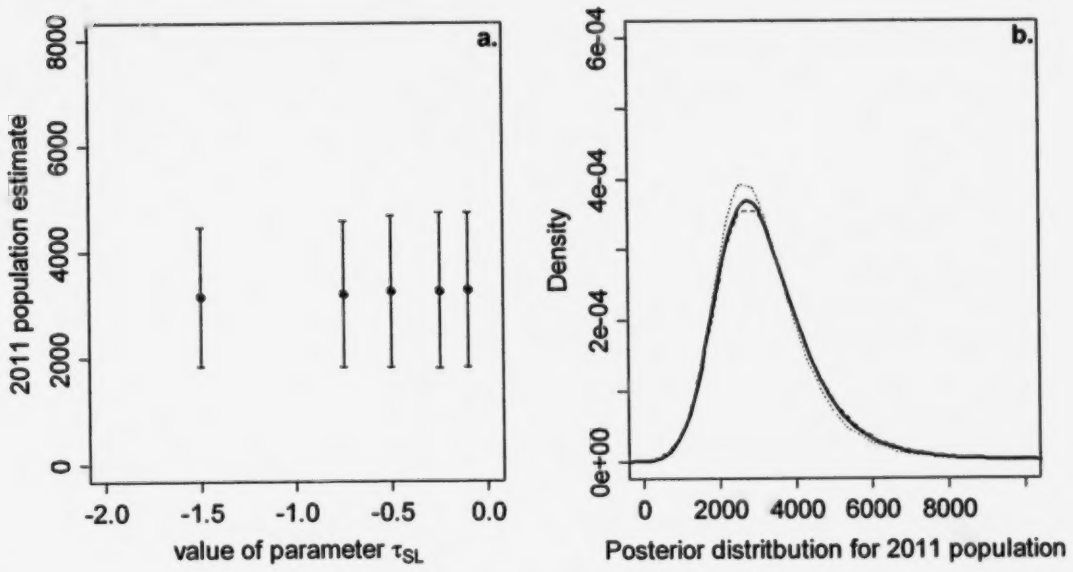

Figure 5. Sensitivity of model population estimates to the hyper-parameter τ_{SL} used in the prior distribution of the struck-and-lost factor. *a) Mean of population estimates (±SE) for five values of τ_{SL}.*
b) Posterior density distribution of 2011 population estimates for τ_{SL} = -0.5 (solid line, value used in main model), τ_{SL} = -1.5 (dotted line) and τ_{SL} = -0.25 (dashed line).

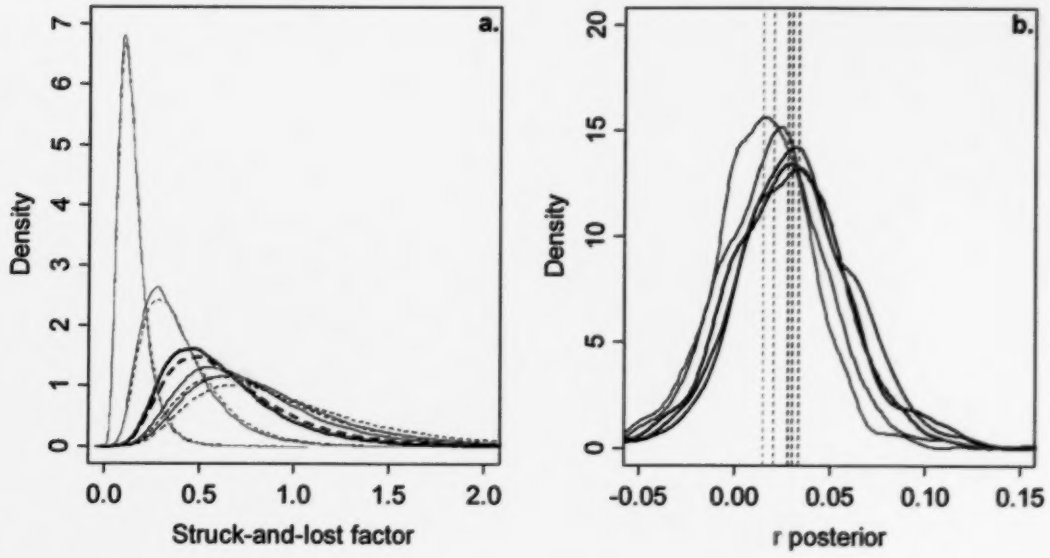

Figure 6. a) Prior (dashed lines) and posterior (solid lines) distributions of the struck-and-lost factor for five values of hyper-parameter τ_{SL} : -2 (orange), -1 (green), 0.5 (black), -2.5 (blue), -0.125 (red). b) Sensitivity of r posterior distributions (solid lines) to five values of struck-and-lost hyper-parameter τ_{SL} (colours as above). Dashed lines: mean values of r (1.46 %, 2.05%, 2.63%, 3.04% and 3.38%).

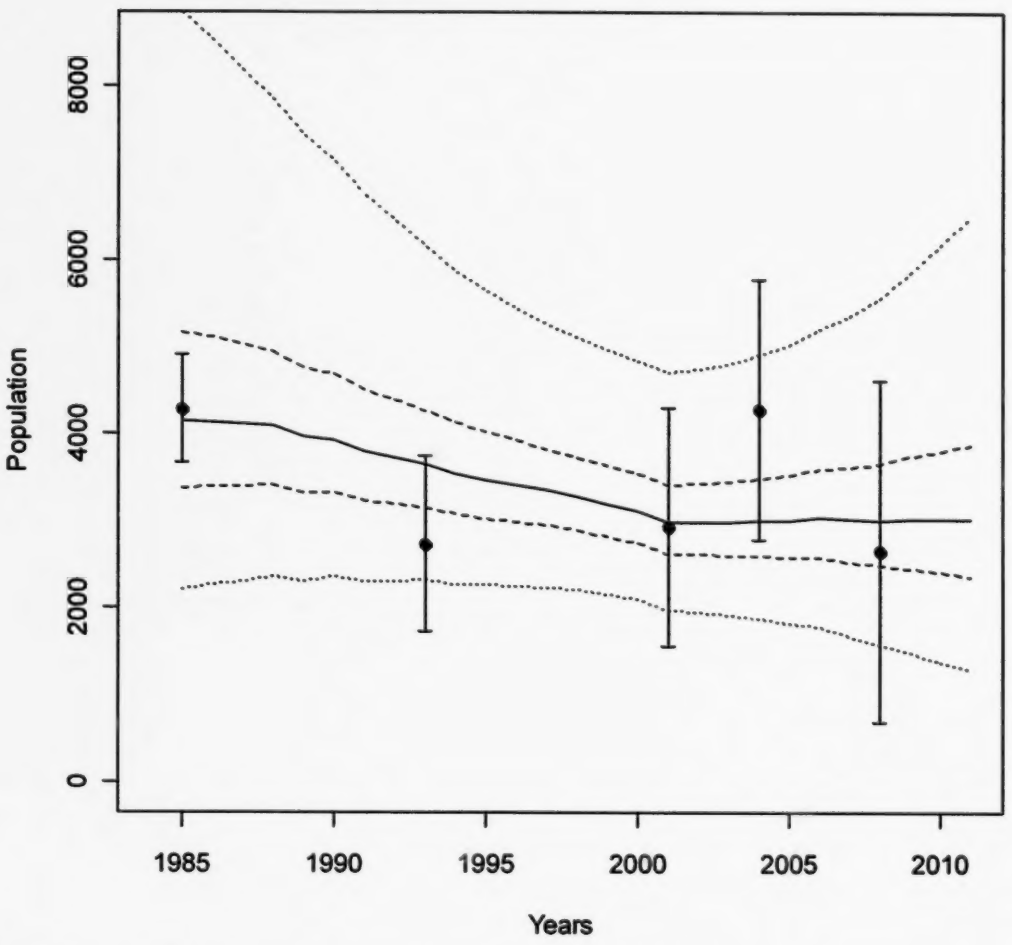

Figure 7. Model estimates of Eastern Hudson Bay beluga abundance. Solid line: median estimates. Dashed lines: 25% and 75% quartiles. Dotted lines: 2.5% and 97.5% quartiles (= Bayesian Credible Interval). The model was fitted to aerial survey estimates corrected for animals at the surface (closed circles, ±SE).

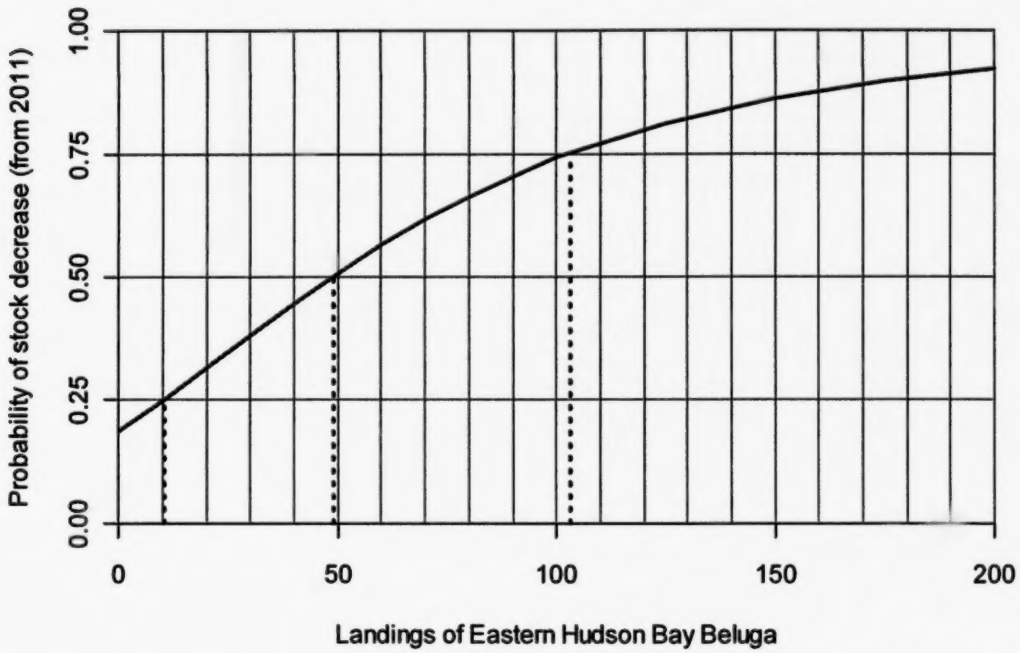

Figure 8. Probability of EHB beluga stock decrease from the 2011 abundance estimate after 10 years of harvest, estimated by stochastic Bayesian stock-production models. Dotted lines indicate levels of harvest corresponding to 25%, 50% and 75% probability of decline.

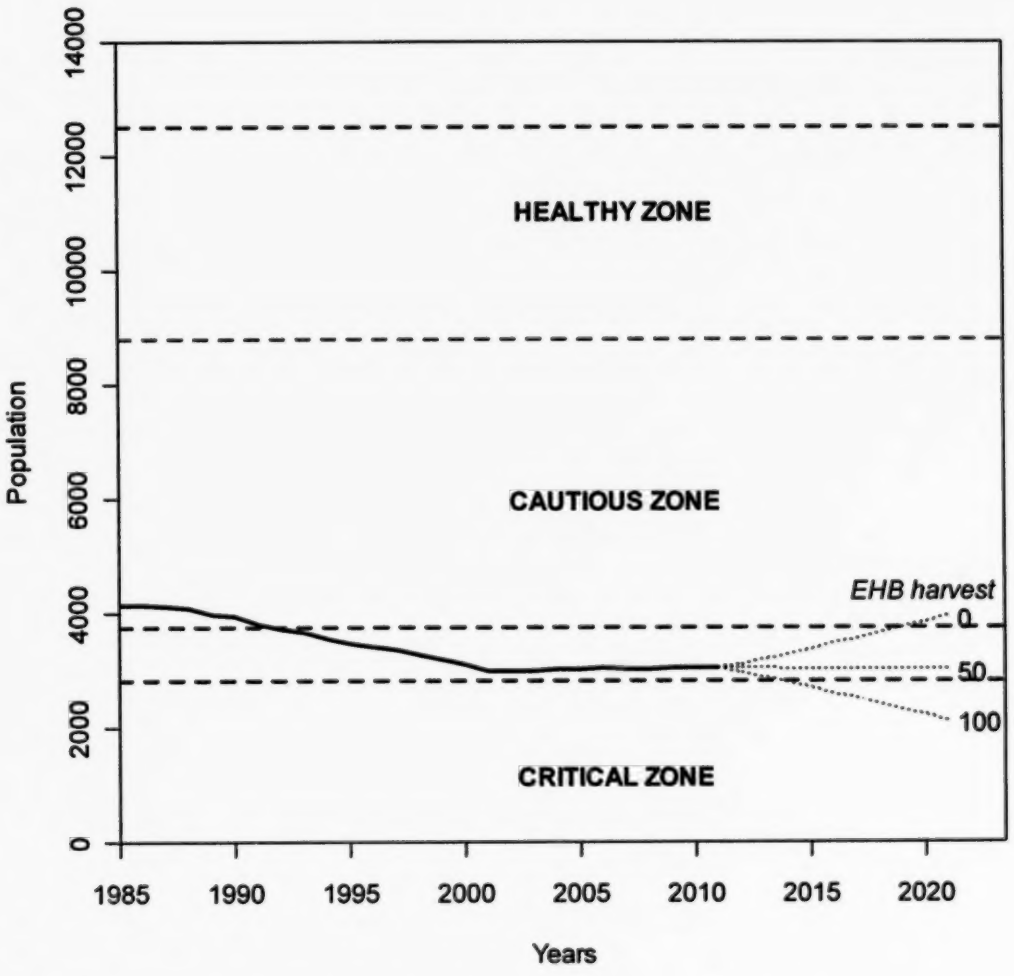

Figure 9. Current estimates of the EHB stock size (solid line) within the context of a possible Precautionary Approach framework (for illustrative purposes). The dotted lines represent future modeled population trajectories at three harvest levels. The upper dashed line represents the estimate of pristine stock size during the 1850s. The middle dashed line represents a precautionary level that separates a healthy zone from a cautious zone where conservation should assume a greater role when establishing harvest levels. The two lower dashed lines represent two possible reference limit thresholds that separate the cautious zone from the critical zone. For a population in the critical zone, conservation should be a priority and harvesting should be reduced to allow population recovery.